The Methanol Economy: Methanol as a Fuel, Chemical Feedstock and a Convenient Liquid Hydrogen Carrier

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The Methanol Economy: *Methanol as a fuel and feed-stock*

High octane (ON = ~ 110)
clean burning fuel, inability to detonate
15.8 MJ/liter.
M-85 Fuel
Liquid Hydrogen Carrier

CH_3OCH_3, high cetane
clean burning diesel fuel, LNG
and LPG substitute.

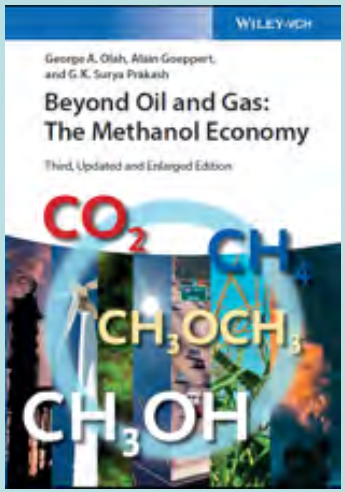
In Internal Combustion Engines

Dimethyl Ether (Diesel and Household Fuel)

CH_3OH
Wood Alcohol

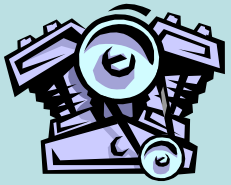
In Direct Methanol Fuel Cells

Conversion to olefins-gasoline, diesel, etc.



Also a good turbine fuel, cooking fuel and a fuel for solid oxide fuel cells.

Methanol in Internal Combustion Engines



- Octane number 100+- fuel/air mixture can be compressed to smaller volume-results in higher compression ratio
- Methanol has also has higher “flame speed”- higher efficiency
- Higher latent heat of vaporization (3.7 times higher than gasoline)- can absorb heat better - removes heat from the engine- air cooled engines. Can be blended with gasoline in various ratio (M5, M10, M15, M85 up to M100)
- GEM fuels, gasoline/ethanol/methanol also possible (Lotus)
- Methanol burns better- cleaner emissions; less NO_x and PM
- Safer fuel in fires than gasoline
- Methanol is a liquid which can be dispensed in regular gas station requiring only limited modifications (unlike H_2)
- Compatible with hybrid (fuel/electric) systems

Race car

Taxi fleet in China

Buses in China

Methanol Reforming to Hydrogen

$$CH_3OH + H_2O \underset{\text{Cat. II}}{\overset{\text{Cat. I}}{\rightleftharpoons}} CO_2\uparrow + 3\,H_2\uparrow$$

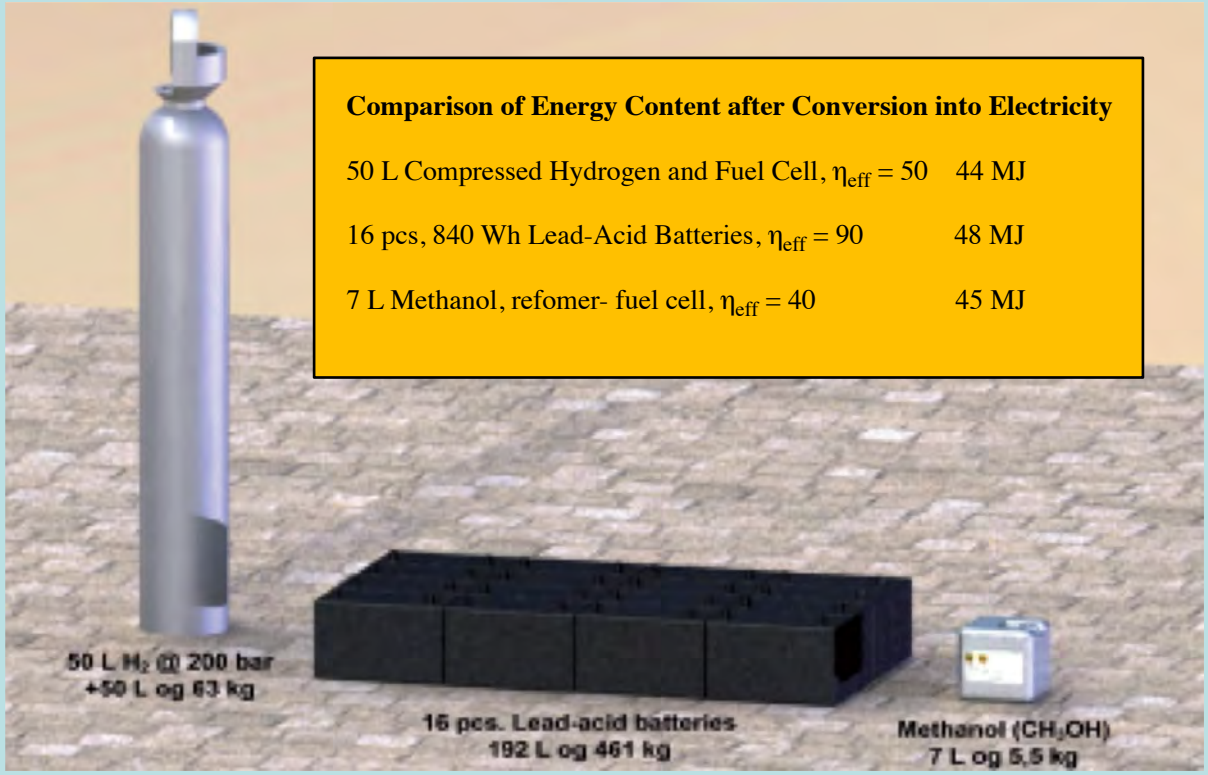
12.1 wt% H_2

Different catalytic systems for forward and reverse reaction

Other C_1 feedstocks for comparison

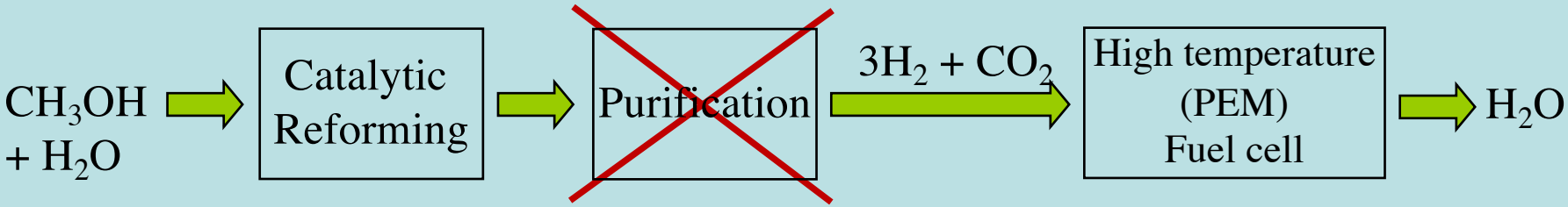
$$CH_4 + 2H_2O \longrightarrow 4H_2 + CO_2 \quad (19\%)$$

$$HCOOH \longrightarrow H_2 + CO_2 \quad (4.34\%)$$



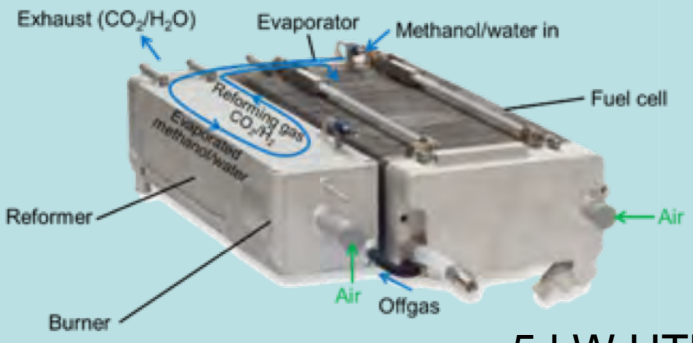
Danish Technological Institute Report

Methanol-powered fuel cell as range extender for electric vehicles



High temperature PEM fuel cell more tolerant towards CO poisoning (*Serenergy*, Denmark).

Can be used as a range extender in electrical vehicles and devices.
Hybrid system has lower weight

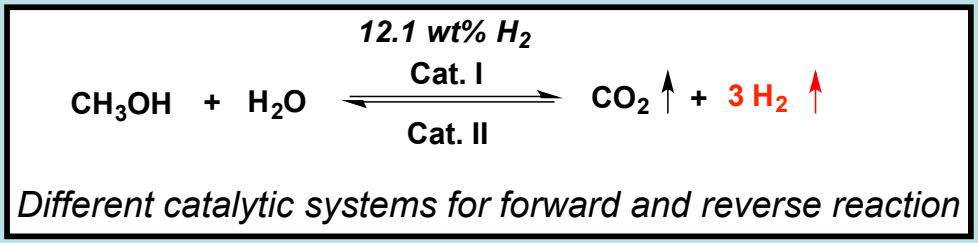


5 kW HTPEM FC

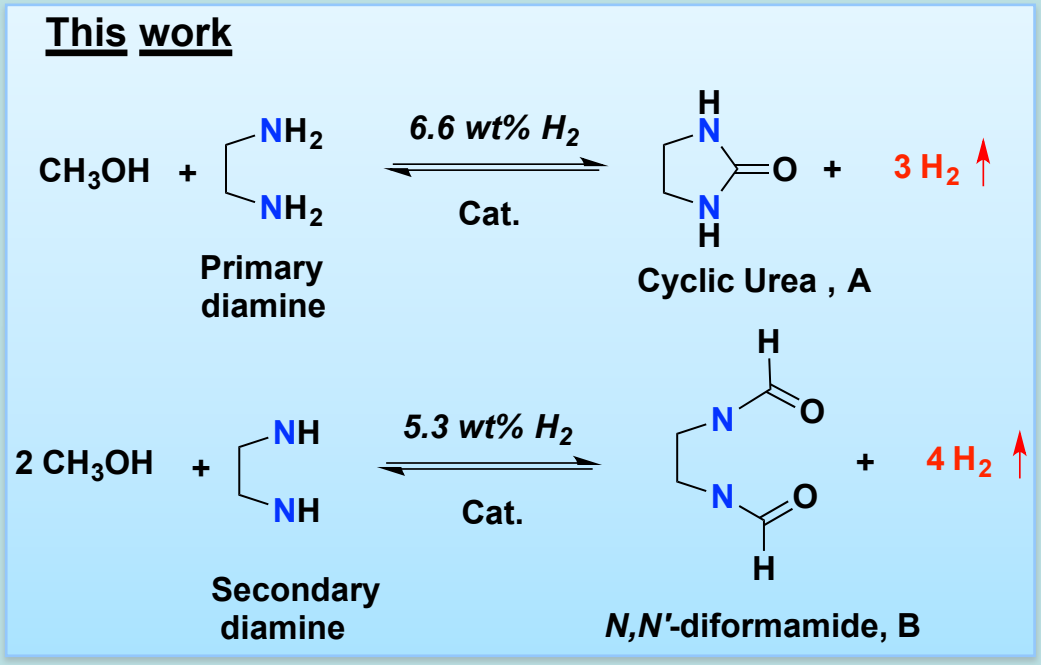
Range extended from about 150 km to up to 800 km with the HTPEM FC range extender

Blue World Technologies, Denmark, 50,000 15 KW stacks, Palcan Motors

Amine-Promoted Reforming of Methanol



Hydrogenation of CO_2 to methanol and the reverse reaction (2011-to date): Leitner, Sanford, Olah/Prakash, Beller, Hazari, Crabtree, Grutzmacher, Milstein and Fujita.



A CO_2-free hydrogen storage approach

- **Carbon neutral cycle.**
- **Liquid fuel at room temperature.**
- **Clean H_2 gas produced – free of CO_2 and CO.**

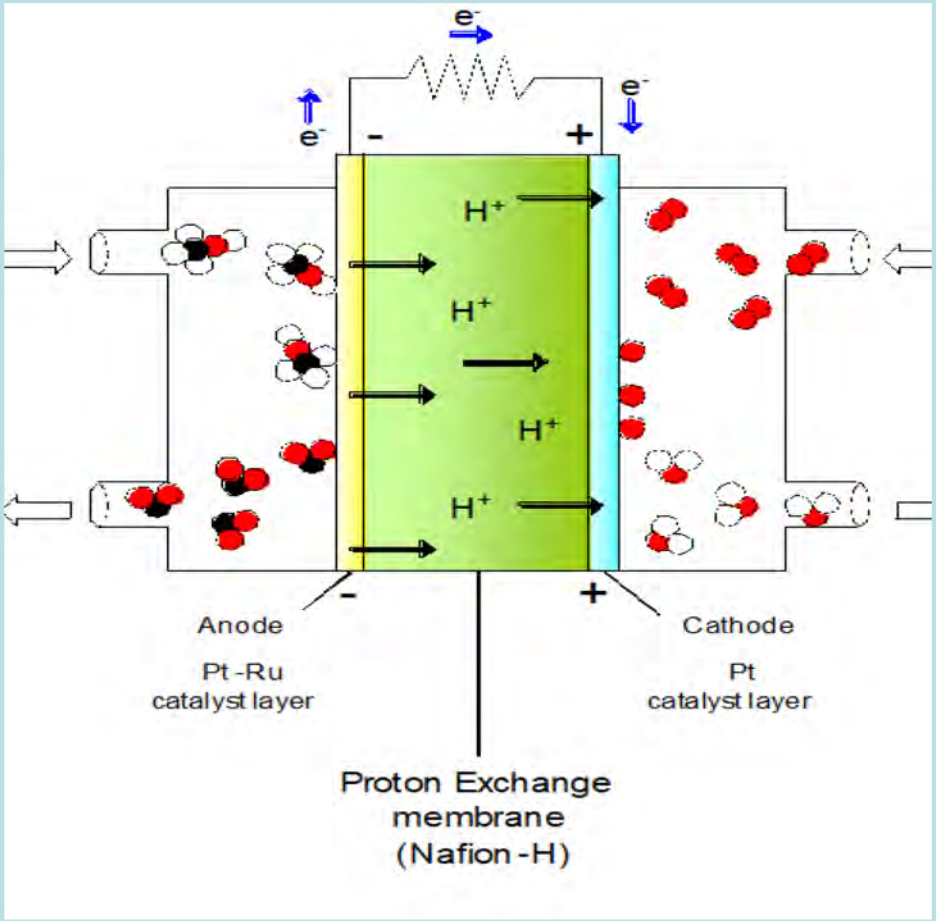
Kothandaraman, J., Kar S., Sen R., Goeppert, A., Olah, G. A. and Prakash, G. K. S. *J. Am. Chem. Soc*. **2017**, 139, 2549-2552.

N-formylation of amines using methanol as a C1 source:

Ortega, N.; Richter, C.; Glorius, F. *Org. Lett.* **2013**, *15*, 1776−1779.

Kim, S. H.; Hong, S. H. *Org. Lett.* **2016**, *18*, 212−215.

Direct oxidation methanol fuel cell (DMFC) USC, JPL - Caltech



Anodic Reaction:

$$CH_3OH + H_2O \xrightarrow{\text{Pt-Ru (50:50)}} CO_2 + 6\,H^+ + 6\,e^-$$

$E^o = 0.006$ V

Cathodic Reaction:

$$3/2\,O_2 + 6\,H^+ + 6\,e^- \xrightarrow{\text{Pt}} 3H_2O$$

$E^o = 1.22$ V

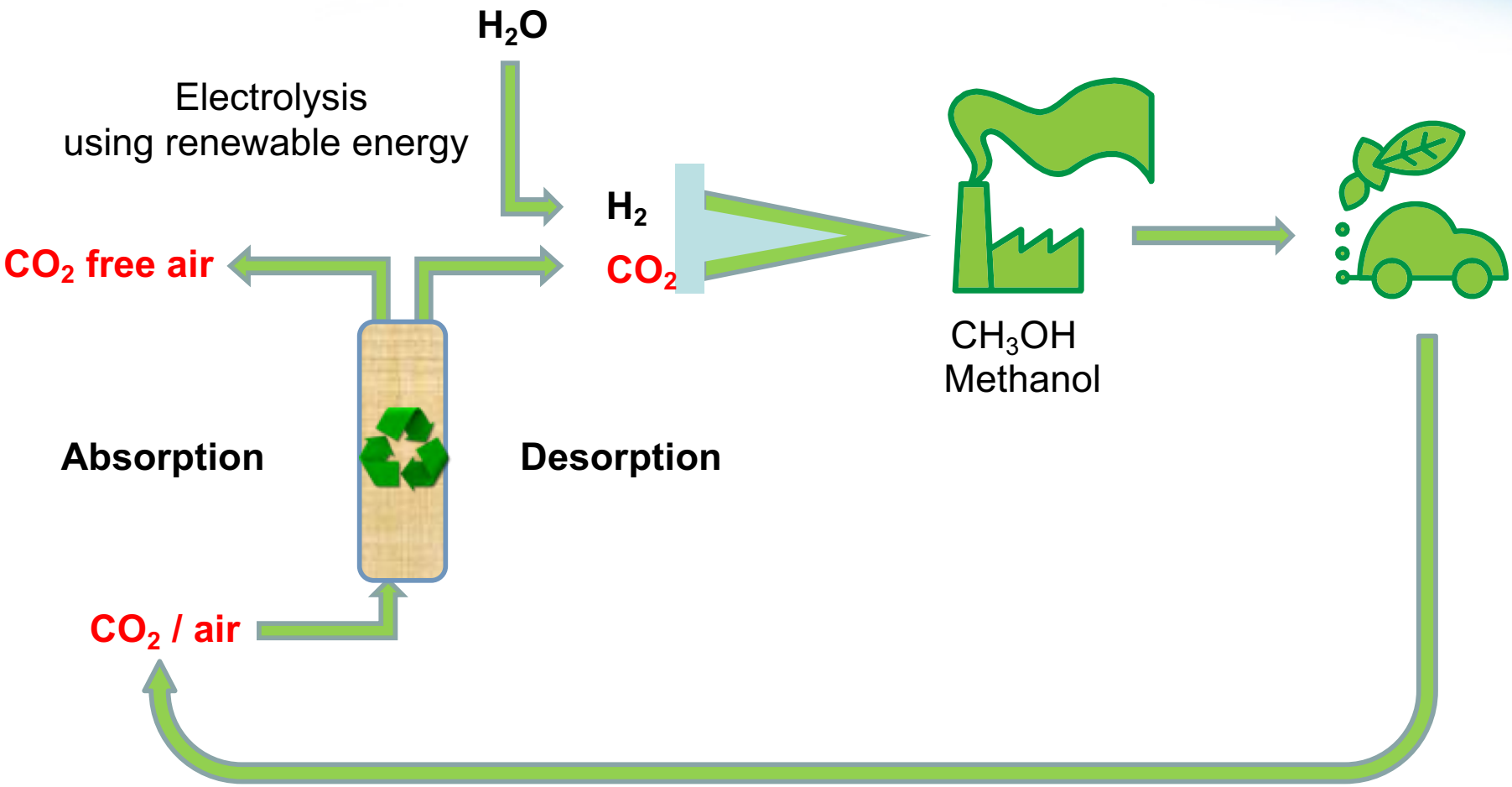
Overall Reaction:

$$CH_3OH + 3/2\,O_2 \longrightarrow CO_2 + H_2O + \text{electricity}$$

$E_{cell} = 1.214$ V

US Patent, 5,599,638, February 4, 1997; ***Eur. Patent*** 0755 576 B1, March 5, 2008.

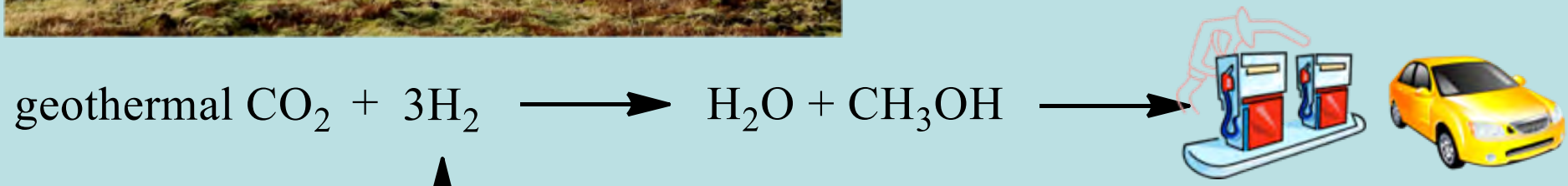
Capture of CO_2 from the Air and Recycling to Fuels and Materials



Geothermal Methanol from CO_2

CRI Carbon Recycling International

"George Olah CO_2 to Renewable Methanol Plant"
HS Orka Svartsengi Geothermal Power Plant, Iceland
Production Capacity: 12 t/day



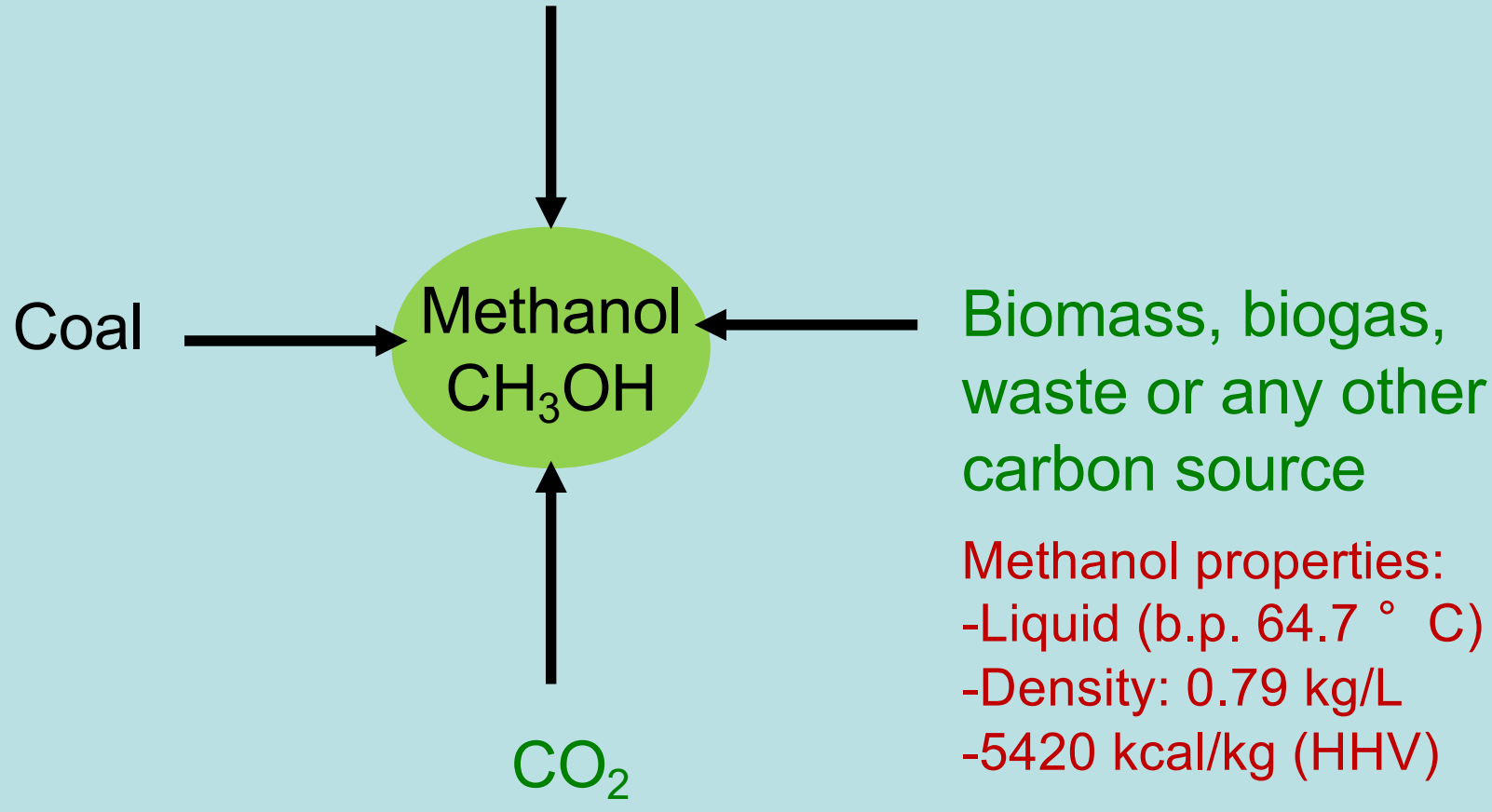
Geothermal methanol sold under the name "Vulcanol"

> 90% reduction in CO_2 emissions compared to gasoline

Electricity cost ~ 1-2 ¢/kWh

About 40 kWh are needed to produce a gallon of methanol (11 kWh/L),
Methanex and Geely are the major share holders

Ubiquitous Methanol, a Fuel, Feedstock and Hydrogen Carrier!



Methanol properties:
-Liquid (b.p. 64.7 ° C)
-Density: 0.79 kg/L
-5420 kcal/kg (HHV)

CH_3OH → CH_3OCH_3 Dimethylether (DME)

KISS Principle, Bridge fuel in the short term and
Renewable Carbon Neutral Fuel in the long term!

If Carbon is the Problem, Carbon is the Solution!